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RRA Heat Treatment of Large Al 7075-T6 Components

by

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ABSTRACT
Retrogression and re-aging (RRA) is a heat treatment process performed on the aluminum alloy 7075 in the T6xxx temper condition to improve its resistance to corrosion, while at the same time maintaining the high strength levels required for aircraft structural applications. For large extruded or forged parts, we have determined that the most practical process involves retrogression at 195°C for 40 minutes, followed by rapid cooling and full re-aging at 120°C for 24 hours. After an RRA treatment of a large extrusion (a three-metre section from a CC-130 sloping longeron), we measured a shrinkage of approximately 0.015%, with minimal distortion damage. There is a small loss of strength, e.g. the RRA yield strength is typically 515 MPa compared to 530 MPa for the same material in the T-6 condition. The corrosion resistance measured both by exfoliation and stress corrosion cracking are significantly better than for the T-6 condition and approach that for the over-aged T-73 condition. Furthermore, the fatigue resistance and fracture toughness of RRA treated material are both within the scatter bands for the T6 condition. For many thick section extrusions and forgings, rework specifications allow for the removal of up to 10% of the material thickness to remove service-exposed corrosion damage (after which the part must be replaced). Hence, the small penalty in strength experienced after the RRA treatment is more than compensated for by improved corrosion resistance, which can eliminate the need to remove corroded material.

INTRODUCTION
The aluminum alloy 7075 in the peak aged heat treatment condition T6xxx (subsequently referred to as T6) has been widely used for structural applications in many aircraft designed in the 50's and 60's. Many of these aircraft are still flying and several models, including the CC-130, are still in production. Corrosion damage is often the reason why 7075-T6 components are replaced in older aircraft, and hence, new parts in this alloy are still available. When improved corrosion resistance is required, alloy 7075 is often used in the over-aged temper T73, but in comparison to 7075-T6, there is a strength penalty of 10 to 15 % which precludes use of the T73 temper when high strength is required. An alternative is to perform the retrogression and re-aging (RRA) heat treatment on parts purchased in the T6 condition. This process was first reported by Cina [1] and over the past twenty years, has been shown to improve corrosion resistance to levels approaching those of the T73 condition while maintaining the strength at levels at or slightly below the T6 condition [2-14]. The first phase of the present work on the RRA treatment of sections of a sloping longeron from the CC-130 (Hercules) aircraft has already been described in a limited NRC report [15], and in two papers [16,17] which cover a background review and detailed results. Some of that work is also included in this paper for completeness together with further tests that have recently been completed.

The CC-130 sloping longeron is a long (9 m) primary structural component in the fuselage of the aircraft. It is roll formed and extruded to the T651 condition, machined and delivered with a coat of epoxy primer and zinc/chromate paint. During the current research programme, we have prepared two open literature papers which describe a range of RRA treatments that were applied to pieces of a longeron (taken out of service due to corrosion damage) [16] and also to new extruded angle material [17]. Results of tensile, fatigue, exfoliation and stress corrosion cracking tests were reported. While some treatments gave better corrosion resistance and some gave better tensile strengths, the most practical RRA treatment for parts of thickness 8.5 mm and above is retrogression at 195 +/-2 °C for 40 minutes followed by re-aging at 120 °C for 24 hours. For parts 4 to 8.5 mm thick a retrogression of 195+/-2 °C for 30 to 35 minutes should be adequate. Rapid cooling after retrogression is required to limit the growth of strengthening precipitates such as $MgZn_2$ which develop during the treatment. Water or glycol quenches are

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preferred for maximum cooling efficiency which leads to maximum strength, but forced air cooling with jets of compressed air is just about as effective and in some circumstances, much more convenient.

The stability of the various phases and microstructural reactions occurring during RRA processing, particularly with respect to resistance to stress corrosion cracking, have been described by Thompson et al [2]. Danh et al. [3] showed that the microstructural processes leading to the enhancement of properties of 7075-T6, consist of:

1) partial dissolution of the GP zones
2) formation and growth of η' particles, and
3) coarsening of grain boundary precipitates, which are primarily η particles.

Wallace et al.[4,5] reported that there are three basic phenomena associated with the increase in corrosion resistance of 7X75-T6 after the RRA treatment:

1) The dislocation density in the RRA treated 7X75 is much lower than that in the T6 condition. This has also been observed by Cina [18]
2) The grain boundary precipitate size and spacing are increased during the RRA treatment and become more effective as sites for the coalescence of hydrogen.
3) After the RRA treatment, the alloy contains a high volume fraction of η' with small amounts of η precipitates. GP Zones may also be present [6]. The η ' particles are said to be responsible for the strength of the alloy while the η particles located at grain boundaries are responsible for the alloy's corrosion resistance [2]. Therefore, as the volume fraction of these grain boundary precipitates increases, so does the resistance of the alloy to SCC [7]

EXPERIMENTAL WORK

The experimental work was performed on alloy 7075-T6xxx in four forms with appropriate designations LN, EA, EC and SP as follows:

LN: sections of a service-exposed sloping longeron from the CC130 aircraft, extruded, variable section thickness 8 mm to 25 mm, T6511 (much of the work on this material has already been published - for complete details see reference [16]).

EA: straight lengths of new extruded angle, 101 x 76 x 7.8 mm thick, T6511 (some of the work on this material has been published in reference [17])

EC: straight lengths of new extruded channel, 101 mm wide, 6.3 mm thick, T6511

SP: a stepped bar of different thickness along the length, machined from a 25.4 mm thick plate, 7075-T651.

7075-T73 plate material was tested in some cases to provide comparable results.

In the total programme, a number of variables in RRA processing have been studied [15-17]: *note - not all variables are discussed in this paper.*

(i) method of heating (oil bath, electric furnace)

(ii) temperature of retrogression (180 °C to 220 °C, but only temperatures of 190, 195 and 200 °C were reported in [16] as other temperatures did not provide adequate tensile strengths)

(iii) time of retrogression (seconds to hours depending on temperature, but 30 to 60 minute treatments were selected for further study)

(iv) time of post retrogression aging treatment (0, 6, 12, 18 and 24 hours) [17].

All measuring equipment conformed to AMS 2750 *Pyrometry* and furnace characteristics conformed to AMS 2770 *Heat Treatment, Wrought Aluminum Alloy Parts.*

Before 7075-T6 structural parts can be replaced in service with 7075-RRA treated parts, it is important to determine that the RRA material conforms to the mechanical property requirements of MIL-HDBK-5. Many of the tests described below are listed in MIL-HDBK-5; other tests were included to determine metallurgical characteristics of the RRA material, since it was felt that such information could lead to an understanding of the structural potential if for example the RRA strength was slightly below the MIL-HDBK-5 levels.

The 7075 alloys from several sources used in this study were all subjected to chemical analysis using a Spectrolab Optical Emission Spectrometer (OES). The results were compared against two reference standards, one from NIST and the other from Alcoa, and all compositions were within the allowable limits.

All the results presented below are for tests on the LN, EA, EC or SP material in the as-received (AR) condition and after RRA treatment. Unless otherwise indicated, retrogression treatment is at 195 °C for 40 minutes followed by water quench (W), glycol quench (G) or air quench (A), and re-aging is at 120 °C for 24 hours. An RRA treatment designation **LN-195/40W-12** means the material was from the longeron, received a retrogression at 195°C for 40 minutes, water quenched, followed by aging at 120°C for 12 hours. If a designation such as 195/40W does not include the aging time, it should be assumed that aging is for 24 hours.

The goals of the program were to achieve mechanical properties meeting the requirements of MIL-HDBK-5 for 7075-T6511 extrusions. While it has not been possible to cover all the required properties with the resources available, the results presented do compare favourably with the goals.

TESTING PROCEDURES AND RESULTS

Electrical Conductivity

Electrical conductivity was measured after each heat treatment and compared to the basic T6xxx values. It is well established that for aluminum alloys, heat treatment conditions which give rise to good corrosion resistance also display higher values of electrical conductivity [19,20], so conductivity is an important monitor. Conductivity was measured using an Autosigma 2000 eddy current meter which utilizes a hand held probe to measure the conductivity in units of %IACS (International Annealed Copper Standard). The conductivity was measured in at least six random locations on each sample and then averaged to obtain a conductivity number for the whole piece. Careful attention was paid to ensure that conductivity measurements were not taken near the edge or at thin sections, so that the electric field of the probe stayed in the metal. The electrical conductivity of 7075-T6 was found to be about 33.5 %IACS, rising to 38 to 39 %IACS after retrogression, and remains at that level after subsequent re-aging. The value for 7075-T73 is required to be 38 %IACS minimum, but is typically about 40 - 42 %IACS. Measurements for several RRA conditions along with the equivalent corrosion results have already been fully reported [16,17]. Long-term (up to 4 months) conductivity stability tests were performed on various RRA treated coupons and it was found that the values were stable over that period [15].

Exfoliation Corrosion

Exfoliation tests, performed according to ASTM G34 *Exfoliation Corrosion Susceptibility in 2XXX and 7XXX Series Aluminum Alloys (EXCO Test),* were used to evaluate the exfoliation corrosion resistance of various conditions of the L and EA material (as-received T6; retrogressed; retrogressed and re-aged; T73) by exposing specimens to an acid saline solution for 48 hours. The EXCO solution consists of NaCl (4.0M), KNO_3 (0.5M), and HNO_3 (0.1M). At least two coupons were prepared for each material/condition tested. The corroded samples were then compared to photographs supplied with the ASTM standard to determine the degree of corrosion. Even though it is a comparative test, the results were reproducible and different observers independently agreed on the results. The EXCO Test classifications in order of decreasing corrosion resistance are N (no appreciable attack), P (pitting), and EXCO (exfoliation corrosion) A, B, C, and D. Various RRA treatments were exposed (190/30W, 190/60G, 195/40G, 200/30W) and little difference was found in the exfoliation performance. The results for the LN material are found in [16] and for the EA material, RRA treatments of 195/40W-24 and 195/40A-24 both gave outstanding exfoliation results, namely that in all tests the rating obtained was P. Not even one coupon exhibited EXCO A or worse.

In summary then, it can be stated that exfoliation resistance after RRA treatments is similar to 7075-T73 i.e. "Pitting", while 7075-T6 performance was much worse, i.e. EXCO B or C.

Salt Spray Tests

Salt spray tests were conducted on EC material in the T6511 and RRA 195/40-24 conditions, according to the requirements of ASTM G85 *Practice for Modified Salt Spray (Fog) Testing.* Preliminary results confirmed the exfoliation results (above) in that various RRA treatments increased resistance to the acidified salt spray as compared to the T6 condition. By exposing different depths to the salt fog it was determined that the RRA treatment was able to provide good corrosion protection through a one cm section thickness, although the pitting corrosion resistance at the outer surface was slightly better. This could be important if fastener holes need to be drilled into a part after treatment.

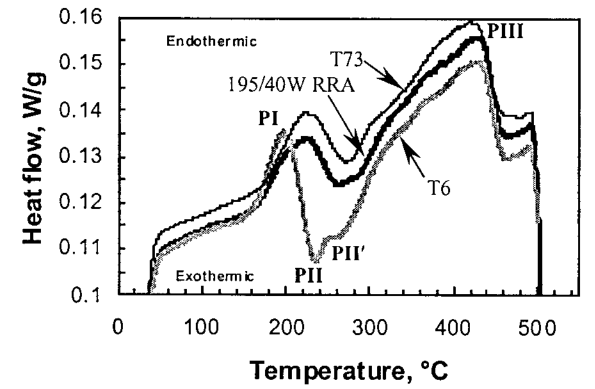
Stress corrosion

Stress corrosion tests on the LN longeron material, were conducted according to ASTM G 38 *Making and Using C-Ring Stress-Corrosion Test Specimens*, machined such that loading was applied in the short transverse direction and the crack formed in the longitudinal (extrusion) direction. The C-ring samples were stressed to 75% of the yield point value of 7075-T6 and then tested according to ASTM G44 *Evaluating Stress Corrosion Cracking Resistance of Metals and Alloys by Alternate Immersion in 3.5 % Sodium Chloride Solution,* i.e. cycling between immersion for 10 minutes and exposure to air for 50 minutes. This process was repeated every hour for 20 days. The samples were checked at the same time every day for cracks and to ensure that no appreciable evaporation had occurred in the test solution. The stress corrosion resistance was rated by the average number of days that a heat treatment could withstand the test before cracking. Cracks were usually of a length of 1 to 2 mm, and located along the back surface of the C-ring specimen.

The results [16] can be summarized as follows: 7075-T73 specimens were able to withstand 20 days without cracking. 7075-T6 specimens all cracked in the first 5 days and the best RRA results were for the 190/50W-24 and190/60W-24 treatments, where all 24 of the specimens survived the full 20-day test. For the 195/40W-24 treatment, only one survived for 20 days, and the other four cracked between day 18 and day 20. In summary, the RRA performance almost matched the T73 results, which is in agreement with earlier SCC results on notched cantilever beam specimens of alloy 7475 [4].

Calorimetry

As mentioned above, the strength of 7075 in various tempers has been ascribed to various precipitates, and the sequencing of precipitation in the microstructure can be determined by differential scanning calorimetry, DSC, [6,11,21-23]. Several T6 and RRA specimens were subjected to DSC (TA Instruments model DSC-2910) by heating a specimen (of known mass) and producing a curve of heat flow (watts per gram) vs. temperature shown in **Figure 1**.



Temper	PI	PII	PII′	PIII
T6511	194	235	262	437
RRA	230	261	281	438
T73	235	277	-	425

Figure 1: DSC curves for 7075-T6, 7075-T73 and 7075-RRA 195/40W materials. The characteristic peak temperatures for each curve are shown in the table.

This curve is of a similar shape and has similar features to the heat capacity/ temperature curve reported by DeIasi et al. [21] who summarized the temperature ranges for the primary reactions as follows: **for T6** - *113-217°C = GP zone dissolution, 217-250°C = η' formation + η' dissolution + η formation, 250 - 271°C = growth of η particles, 271-448°C = η dissolution;* **for T73** - *164-245°C = η' dissolution + η growth, 245-442°C = η dissolution.*

In the present case, for the T6 and T73 conditions the temperature ranges were similar, and the peak temperatures PI etc. were very similar to those reported by Baldantoni [6] who studied 220/1W to 220/6W retrogression treatments. The main reason for performing this analysis was to verify the 7075-T6 condition and to determine whether the curve for the 195/40W RRA treatment was similar to that for the T73 condition (i.e. the endothermic dissolution and exothermic precipitation reactions occurred at the same temperatures). Figure 1 clearly shows this to be the case, supporting the conclusions of Baldantoni [6] that RRA treatments (i) complete the dissolution of the GP zones and (ii) - as indicated by the increase in PI temperature - increase the volume fraction of the η'. In the present work, there appeared to be no difference in the DSC response at depths up to one cm below the surface.

Tension Tests

Tension testing was carried out in accordance with ASTM E8 *Tension Testing of Metallic Materials.* Due to material constraints both full size and sub-size specimens were used, and specimens were prepared with the tensile axis in the longitudinal (L) and long transverse (T) directions. A cross-head speed of 2mm/min was used. The 0.2% offset yield strength, ultimate tensile strength and the percent elongation were determined.

For the service-exposed longeron LN material, in the longitudinal direction, tension test results for four different RRA treatments have been reported [16]. In all cases, the ultimate tensile strength (UTS), the yield strength and the elongation results exceeded the minimum requirements of AMS 4169 *Extrusions 7075-T6511.* Note that the AMS 4169 values are the same as the A-basis MIL-HDBK-5 design values [24]. The tensile test results on RRA treated extruded angle material have previously been reported [17]. A summary of those results for the EA as-received (mean of 10 tests) and RRA 195/40W and 195/40A (mean of 20 tests) materials is reproduced in **Table 1** together with MIL-HDBK-5 [24] design values for the same thickness (7.938 mm) extrusions. Although we have not performed enough tests for A- or B-basis statistical

Table 1: MIL-HDBK-5G A-basis mechanical property values for 7075-T6511 extrusions, and test results for the EA 7075-T6511 and EA RRA (195/40W&A-24) materials in the L and T directions.

	Ftu		Fty		Fbru*	Fbry*	e (%)	
	L	T	L	T	L	L	L	T
MIL-HDBK-5 (ksi)	81	78	73	69	146	113	7	
(MPa)	558	538	503	476	1007	779		
EA 7075-T6 (MPa)	613	591	556	530	1080	878	13	13
EA 195/40W (MPa)	583	571	522	515	1079	890	14	15
195/40W-3σ (MPa)	573	569	514	512	1029	803		
EA 195/40A (MPa)	576	568	517	512			14	15
195/40A-3σ (MPa)	568	562	504	506				

* for an edge distance to hole diameter ratio of 2.0

A full definition of the symbols can be found in reference [24], page 1-2, but briefly, Ftu = ultimate tensile stress, Fty = tension yield stress, Fcy = compression yield stress, Fsu = shear stress, Fbru = ultimate bearing stress, Fbry = bearing yield stress, e = elongation.

analysis, we have calculated values for the mean minus three standard deviations for any given condition, which for a small sample is statistically significant. For both the ultimate tensile strength (Fu) and the yield strength (Fty) these values exceeded the A-basis values for both the water quenched and forced-air cooled specimens although water quenching consistently results in higher strength.

Hardness

Although hardness is not considered to be the most reliable indication of the level of heat treat response, Rockwell B hardness was measured both prior to and after each treatment. For the various material sources, the average HRB values for the 7075-T6 condition, the retrogression condition and the RRA (195/40-24) condition respectively were: LN=91,82,90 EA=94,88,92 EC=93,83,90. Rockwell B hardness was also taken on a 19 mm thick section of one of the longeron parts at equal intervals through the thickness to determine if the treatment's effects had penetrated the whole part. These results showed that HRB was constant across the whole section (90+/-1.5) [15].

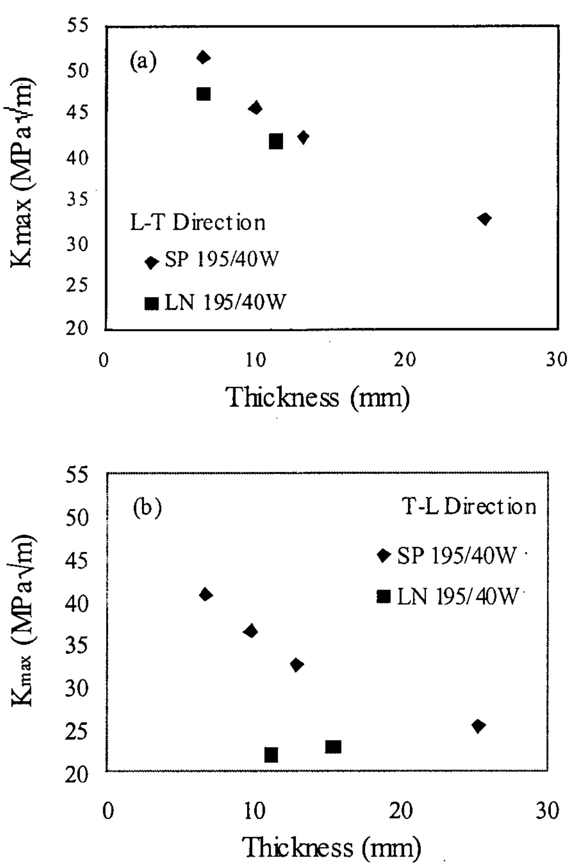


Figure 2: Effect of product form, thickness and specimen orientation on the fracture toughness of RRA treated 7075 aluminum alloy

Fracture Toughness

The material was tested in various product forms and heat-treated conditions as follows:
EA in the -T6511 (as received, AR) condition
EA after 195/40A-24 and 195/40W-24 treatments
LN 7075-T6511 RRA treated 195/40W
SP in the RRA 195/40W condition

Fracture toughness tests were performed in both the L-T and T-L orientations for these materials. All fracture toughness tests were performed in accordance with ASTM E399-*Test Method for Plane-Strain Fracture Toughness of Metallic Materials*. The specimens were compact tension type with characteristic dimension, W=50.8 mm. Loading rates were in the ASTM "slow" regime. Because product forms of various thicknesses were examined, it was not possible to obtain valid plane strain results for the thinner (i.e. most) specimens. Consequently the maximum stress intensity factor K_{max} is reported as the fracture toughness for all material forms and conditions shown in **Figures 2 and 3.**

Figure 2 shows the effect of material thickness on the fracture toughness of the RRA treated materials. In both cases, the fracture toughness in both L-T and T-L directions decreases with increasing thickness. In most cases the measured values are above the typical values for 7075-T6 quoted in the ASM Metals Handbook [25].

Figure 3 shows the effect of product form (EA, SP and LN) and treatment on the relative fracture toughness for specimens of constant (7.8 mm) thickness. Again it is

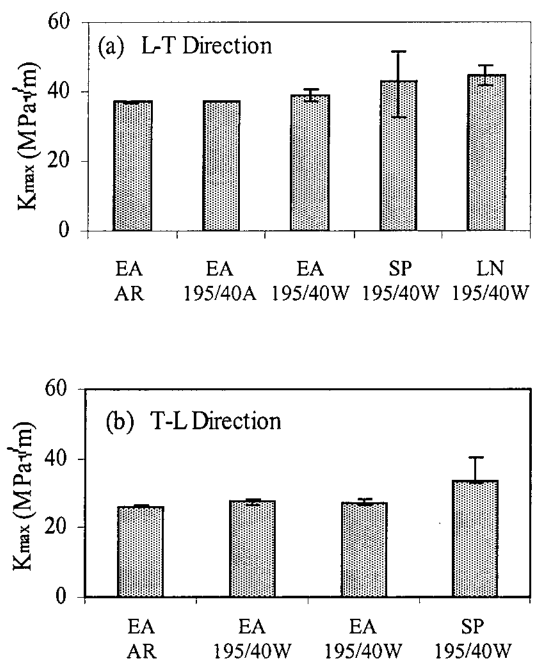


Figure 3: Effect of specimen orientation, quench medium and product form on fracture toughness of RRA treated material.

observed that 195/40W and 195/40A RRA-treated material exhibited fracture toughness at least as good as for the 7075-T6511 temper.

Fatigue

Axial loading (R=0) test The material was tested in axial fatigue using specimens machined from EA in the as-received (AR) T6511 condition. Both 195/40A and 195/40W RRA treatments were examined. In addition, two surface conditions were investigated:

(i) machined and mechanically ground and polished

(ii) as-extruded.

All axial fatigue testing was performed in load control in accordance with ASTM E466 – *Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials*. The specimens had a rectangular gauge section that was 12.3 mm x 4 mm for the machined and polished specimens and 12.3 mm x 7.8 mm for the as-extruded surfaces. The data shown in **Figures 4 and 5** collected in this study for lives clustered around 10^7 cycles represent unbroken specimens (i.e., tests interrupted before fatigue failure occurred).

The loading was repeated tension (R=0) with cyclic frequency between 5-30 Hz depending on specimen life. The fatigue life results are plotted in **Figure 4** for the polished specimens. The figure also shows the fatigue data from MIL-HDBK-5G [24] for 7075-T6xx material at R=0. In general, it can be seen that the RRA specimens exhibit slightly lower fatigue strength than the AR specimens but the data are generally within the scatter of -T6xx data. Also, the water quench appears to give slightly better fatigue strength than the air quench.

The data for the as-extruded surfaces are compared to those for polished surfaces in **Figure 5**. As expected the as-extruded specimens all have lower fatigue strengths than the polished specimens at all stress levels, although at high stresses, the differences are not so pronounced. For the as-extruded condition, the RRA results are practically identical to the as-received T-6 results, so neither benefit nor loss has been derived in this respect by the RRA treatment.

Fatigue Crack Growth

Fatigue crack growth data were measured on EC 7075-T6511 as-extruded channel and on EC 195/40W RRA treated material. The specimens used were single edge notch (SEN) type, 76 mm wide and with the original thickness of the channel extrusions cut from the centre of the backs of the channels. The testing was performed with the loading axis in the L direction. All crack growth testing was done in laboratory air at cyclic frequencies of 10-30 Hz following ASTM E647 –*Test Method for Measurement of Fatigue Crack Growth Rates*.

The crack growth results for 7075-T6511 and RRA (EA 195/40W) materials at several stress ratios and maximum stresses are shown in **Figure 6.** Two maximum stress levels were used for the RRA material, 50 MPa and 30 MPa, and stress ratios of R = -0.3, 0.1, and 0.5 were examined. In Figure 6, for the R values of -0.3, ΔK is the positive portion of the range in accordance with ASTM E467.

The data generally show that the RRA material exhibits slightly greater resistance to fatigue crack growth than the –T6511 material under similar loading. This is consistent with the previous observations that the RRA-treated material is more ductile, has a slightly lower yield strength and higher fracture toughness than the 7075–T6511 material.

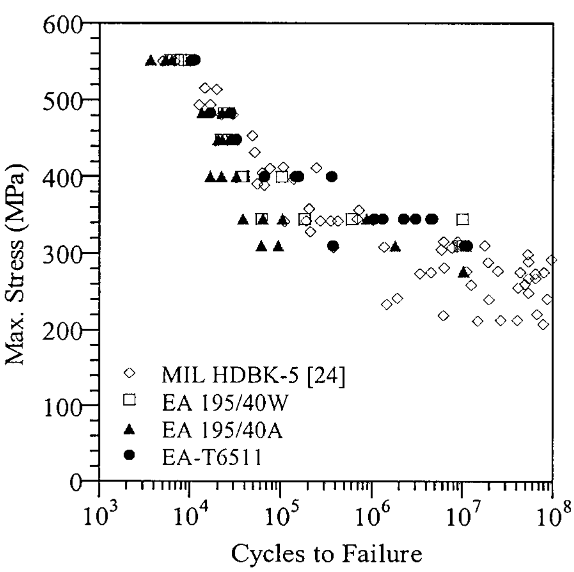


Figure 4: Constant amplitude axial fatigue data at R=0 for 7075-T6511 and after 195/40W and 195/40A RRA treatments.

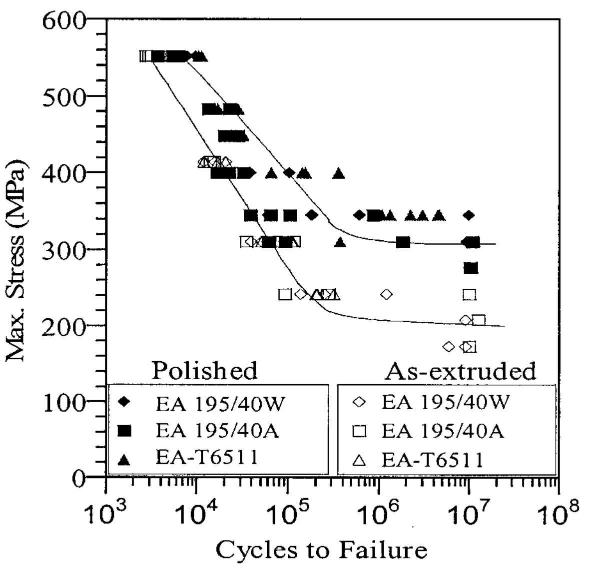


Figure 5: Effect of surface condition on the axial fatigue behaviour of as-received 7075-T6511 and RRA treated materials.

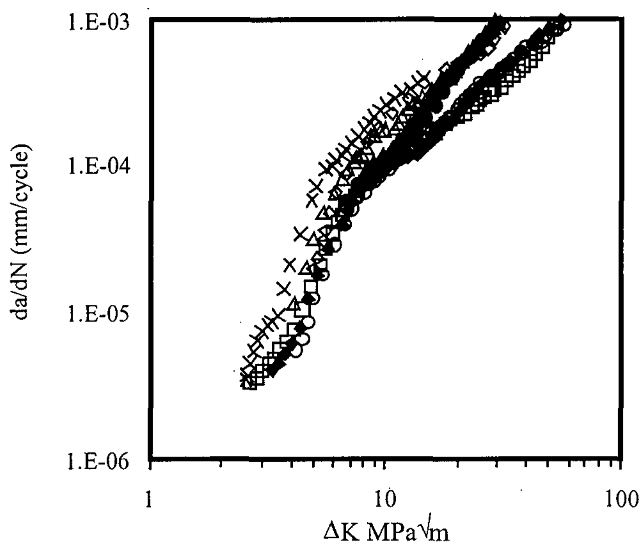


Figure 6: Single edge notch fatigue crack growth data for 7075-T6511 and EA 195/40W RRA treated material.

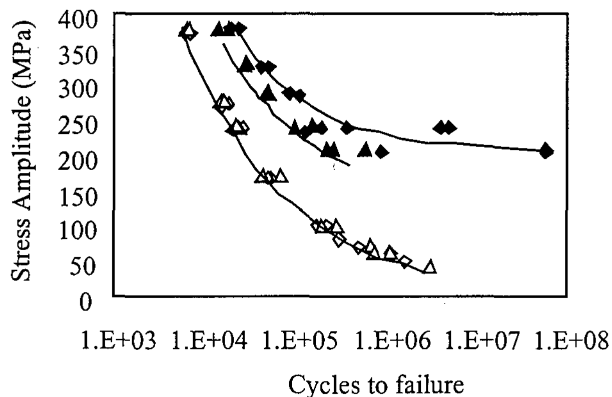


Figure 7: Rotating bending fatigue data for 7075-T6511 and RRA treated material, tested in air and in NaCl solution.

Corrosion Fatigue

Rotating bending (R=-1) constant amplitude fatigue tests were conducted on EA 7075-T6511 and 197/35W RRA treated materials with and without the presence of a corrosive medium. A cantilever-type rotating bending fatigue machine equipped with a mechanism for dripping EXCO solution (see above for formula) on the gauge section of the specimen during cycling was used. The gauge diameter of the specimens was 7.62 mm and loading frequencies of 30-60 Hz were used depending on the fatigue life.

The results of the fatigue tests with and without corrosion are shown in **Figure 7**. The corrosion test is extremely aggressive, and the results show that both the 7075-T6511 and the RRA-treated samples exhibit fatigue lives on the same curve (or in the same narrow scatter-band) under these conditions (open symbols). This indicates that the RRA treatment has slightly improved the corrosion fatigue properties, since the RRA tests in air fall in the lower portion of the scatter-band (closed symbols in Figure 7 which in turn are similar to the axial fatigue results reported above in **Figure 4**). Unfortunately, it was not possible to include corrosion fatigue studies on 7075-T73 in this programme for comparison. As expected, the corrosion fatigue lives are well below the fatigue lives of specimens tested in laboratory air, especially at lower stress levels.

Effect of Pre-Fatigue on RRA treated Materials

Rotating bending fatigue tests were used to determine if the RRA treatment can eliminate or reduce existing fatigue damage. This may be an important consideration for example in choosing whether to perform the RRA treatment on components which have experienced a considerable amount of service exposure, and which might therefore contain fatigue-induced damage. EA specimens were pre-fatigued to 60% of their expected life at several stress levels, then given the 197/35W RRA treatment. The fatigue tests were then continued at the same stress levels. The results were given in reference [17]; at all stress levels, the pre-fatigued specimens fell in the same scatter-band as the T6511 and RRA results, so the RRA treatment had no significant effect on pre-fatigue-induced damage.

Bearing Load

ASTM E 238 *Standard Test Method for Pin-Type Bearing Test of Metallic Materials* is used to calculate the bearing strength of materials under edge loading with a close-fitting cylindrical pin. It is a comparative test used in the design of structures, primarily to determine material performance in the presence of fasteners. The material for the test was EA, both in the as-received T6511 and the RRA 195/40W-24 condition. The bearing load tests were performed on material treated at IAR and tested at SPAR Aerospace on specimens 6 inch (152.4 mm) long, 1.5 inch (38.1 mm) wide and 0.25 inch (6.35 mm) thick. The edge distance (e/D) ratio was 2. Due to specimen thickness and width constraints, a smaller pin than specified in ASTM E238 was used in the tests, which might be expected to result in lower bearing yield (Fbry) and ultimate (Fbru) strengths. However, for both the T6511 (mean for 5 tests; Fbry = 878 +/- 41 MPa, Fbru = 1080 +/- 24 MPa) and RRA (mean for 10 tests;

Fbry = 890 +/- 29 MPa, Fbru = 1079 +/- 17 MPa), the results were comparable to those for 7075-T6 extrusions published in MIL-HDBK-5 [see **Table 1**]. In all the bearing load tests, RRA specimens (with shear-out failures) consistently exhibited about twice the ductility of the T6 specimens, which failed by tensile-cleavage fractures.

Dimensional Stability

Selected parts were analyzed for size and shape both before and after treatment. They were characterized by their profile along one edge and the distances between various fastener holes. A difference in the profile of the part after treatment indicated bending, whereas a difference in the distance between rivet holes indicated shrinkage. The analysis used a Temmis Laser System to identify points on the parts surface with relation to a reference plane. To measure the distance between holes the circumference of the circle was identified with the same system and the center located and projected to a reference plane. Then the distance between the two centers on the reference plane was found. The same procedure was used on each part before and after heat treatment.

The results, which are described in detail in reference [15], can be summarized as follows:
(i) The RRA treatment causes a slight shrinkage - the maximum shrinkage recorded was 0.015%, equivalent to 1.5 mm in a 10 m length;
(ii) The RRA treatment induced a slight bending distortion - the maximum bending distortion recorded over a length of 1.3 m was 0.20 mm, which is minimal and can easily be overcome during installation of a large component.

DISCUSSION

The most important RRA [195/40W-24, and 195/40A-24] results can be summarized as follows:

Corrosion: Exfoliation, salt spray and stress corrosion cracking results for RRA material are always significantly better than for the -T6 condition and approach the performance of the -T73 condition. Several previous studies have come to the same conclusion [2,8,9].

Tension: For the service exposed longeron material, the mean tensile strengths reported in reference [16] for a 195/40G RRA treatment are about 1% above the MIL-HDBK-5 (and AMS 4169) values. The mean values minus one standard deviation (σ) were about 1% below the MIL-HDBK-5 values. However, for new extrusion material (EA) reported herein and in reference [17], 195/40W and 195/40A tensile results for both L and T orientations, for a minimum of 10 tests, indicate that (mean-3σ) values exceeded the MIL-HDBK-5 A-basis values for ultimate tensile strength (Ftu) and yield strength (Fty). There may be several reasons for the better results on the new extrusions - (i) the longeron material, being older, may not have had the (even new) strength of recently manufactured 7075-T6 extrusions; (ii) the service exposure may have weakened the material (e.g. damage incurred in service or during removal) and (iii) the higher scatter in the LN results gives rise to the higher standard deviations.

Although the typical values for as-received T-6 material was always slightly higher (by 3-5 %) than the RRA/W, which in turn was stronger than the RRA/A material, the RRA treatments consistently resulted in higher elongation (14 %) than 7075-T6 material (12 %).

Fracture Toughness Figures 2 and 3: The RRA EA material had the same or slightly higher fracture toughness in the L-T and T-L orientations than the as-received material. Fracture toughness decreased with section thickness.

Fatigue: The fatigue strength of the RRA material was slightly lower than the -T6 material, although the results did fall within the same broad scatter-band as the T6 results published in MIL-HDBK-5. Hence, fatigue should not be a design issue in the selection of the RRA process to improve corrosion resistance. Water quenching after the retrogression step gave better fatigue properties than did air cooling.

Fatigue Crack Growth Rate: the RRA process improved the FCGR which is in agreement with the higher observed ductility so it would be reasonable to assume that the damage tolerance for cracked structures would also be improved.

Physical Characteristics: Since re-aging is a low temperature treatment, distortion is not considered to be a problem, even for large parts. Also, as reported in Reference [16], the RRA treatment does not damage epoxy primer paint either on service-exposed or new parts. Since many new parts are delivered in this condition, it is beneficial that the RRA treatment can be performed without paint removal.

In the present program, over the past four years, a number of different RRA treatments that were performed on various 7075-T6 extrusions have been evaluated and those results have been presented in previous publications [15-17]. It was found that for parts up to 25 mm thickness, the optimum RRA heat treatment was retrogression at 195 °C for 40 minutes, followed by water or glycol quench and aging at 120°C for 24 hours. Similar results have been obtained for 197/35W-24 treatments, but shorter retrogression treatments at higher temperatures, and shorter aging treatments failed to meet the MIL-HDBK-5 requirements for yield strength [17]. Some of the earlier results have been included in this report for the sake of completeness. Results for RRA treated EA material, together with MIL-HDBK-5 A-basis values (for equivalent thickness extrusions) are presented in **Table 1.** Due to lack of resources, compression and shear tests have not been performed in this programme even though these properties are included in MIL-HDBK-5. However, for all tests where ductility is a factor, (tension, bearing load, fracture toughness) the RRA ductility was higher than that for the -T6 condition, so the RRA results for compression and shear tests would be expected to be favourable.

From Table 1 it can be seen that mean values (determined from 10 to 20 tests), both for the new, EA as-received 7075-T6 material and the RRA treated material all exceed the MIL-HDBK-5 A-basis values by at least 3σ (i.e. 3 standard deviations). Although we have not performed enough tests for an A-basis statistical computation, mean-3σ can be considered to be a conservative approximation. For the service -exposed LN material, the tensile strengths were marginally lower, so RRA treatment for service-exposed material is only recommended for components that are life-limited by corrosion. Note that in order to generate A- and B-basis design allowables for the RRA heat treatment process an extensive test program would have to be undertaken. Statistically valid sample sizes would address variability in product forms (plate, bar, extrusion, forging), grain direction (L, LT) and production lots.

When choosing an optimum RRA heat treatment for a structural component, the tensile strength results are considered the most important as tension values are used as one of the main selection criteria for design purposes. Hence, although the 190/50W & 190/60W RRA treatments gave better SCC results, the tensile results for 195/40W were better. In cases where 7075-T6 components are removed from service because of corrosion damage, then there is a strong case for performing the RRA treatment on the new part prior to installation. It is estimated that the life could be tripled before equivalent corrosion is incurred. Even for fatigue- or tension-loaded critical components, there may be justification for accepting small fatigue and strength penalties of the RRA material if corrosion has been found to be the life limiting factor. Obviously each case will have to be considered individually, but it should be noted here that many component drawings do allow for the removal of corrosion damage by grinding (sometimes up to 10 % of the section thickness in thick forgings and extrusions), so 7075-T6 components which are thus designated, are particularly strong candidates for the RRA treatment.

Some thought has been given to performing the RRA treatment on service exposed components and returning them to service. This practice is not recommended except as a temporary measure if new parts are not available.

It is hoped that in the near future, an RRA-treated (small) component will be installed on the CC-130 aircraft during a routine overhaul. The selected part will be corrosion-prone and will be readily and regularly inspected for a period of three years, during which time, in the -T6511 condition, it might be expected to show signs of corrosion damage.

CONCLUSIONS

1. For 7075-T6 extrusions of up to 25 mm thickness, the optimum RRA heat treatment is retrogression at 195 °C for 40 minutes, water quench and re-age at 120 °C for 24 hours. Compared to the 7075-T6 condition, the RRA treatment:

- Significantly improves the corrosion resistance.
- Improves ductility, fracture toughness, and fatigue crack growth rates and slightly improves bearing load strengths and possibly corrosion fatigue resistance.
- Slightly decreases (by approx. 2%) the tensile strength, tensile yield strength and possibly also the fatigue strength.

2. Hence the RRA process is ideally suited for 7075-T6 parts and components which are usually replaced due to corrosion problems. Where tensile strength or fatigue resistance are critical, water quenching after retrogression is required, but when corrosion is the main cause for concern, parts may be forced-air cooled after retrogression either for convenience or if a slight shrinkage cannot be tolerated.

3. There is a slight penalty in strength when RRA treatments are given to (older) service-exposed material, so the treatment in this case should be limited to those parts which are not strength or fatigue critical.

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Paper 7

Question by Mr. Frank ABDI

Introduction of heat treatment might change grain size?

Author's reply

We have not found any change in the grain structure after performing the RRA treatment

Question by Frank Abdi

What is the composition of new precipitate material, and what temperature is it formed?

Author's reply

We have not performed any analysis of the fine precipitate particles which form during the RRA treatment. The scanning calorimetric results indicate that the precipitate reactions are similar to those occurring during the T73 heat treatment.

Question by I.G. Palmer

What is the current patent situation with regard to RRA treatment?

Author's reply

Alcoa hold a number of US patents for a "three step aging process" for 7xxx series alloys which closely resembles the RRA treatment. Early NRC work is cited as a reference for prior work. I do not know of any patent coverage in Europe.

Question by I.G. Palmer

Are the problems in applying RRA treatments to thick sections in 7075-T6 due to quench sensitivity effect? is the process more effective in the newer, less quench sensitive 7xxx alloys?

Author's reply

We are only working with 7075 - T6 as this is the alloy of concern in aging aircraft. To date we have only examined parts of section thickness up to 19mm thick, for which the RRA process works. well. We are planning to do work on thicker sections in the near future.